

**Memo**

<b>Date:</b>	April 12, 2007	<b>Project:</b>
<b>To:</b>	Rohan McGowan Jackson and Vicky Peacey (Kennecott Utah Copper Corporation)	
<b>From:</b>	Rich Borden (Manager Mineral and Non-Mineral Waste Rio Tinto HSE) and Mark Logsdon (Geochimica Incorporated)	
<b>Subject:</b>	<b>REVIEW OF POTENTIAL ACID ROCK DRAINAGE MANAGEMENT OPTIONS FOR THE KENNECOTT UTAH COPPER WASTE ROCK DUMPS</b>	

Acid Rock Drainage (ARD) is generated from the waste rock dumps at the Bingham Canyon Mine. Kennecott Utah Copper (KUCC) is committed to the long-term collection and treatment of this water, but is also interested in exploring other management options to control ARD at the mine. This technical memorandum reviews potential ARD management strategies and identifies those strategies which show the most promise for reducing ARD risks under the site-specific conditions of the Bingham Canyon waste rock dumps.

**Setting**

The waste rock dumps at the Bingham Canyon Mine contain approximately 4.2 billion tons of waste rock and cover more than 5000 acres. According to current mine plans an additional 0.9 billion tons of waste rock will be generated before closure. The great majority of the waste rock contains low (<2%) sulfur concentrations primarily as reactive pyrite ( $FeS_2$ ), but there is usually little neutralizing capacity so most of the rock generates acid rock drainage.

The mine is located in the Oquirrh Mountains and the dumps have been constructed as valley fill and by advancing tall angle of repose slopes out from mountainsides. The waste rock piles are commonly greater than 500 feet high and they have complex internal structures created by truck dumping and earlier rail dumping. The dumps contain steeply dipping, discontinuous coarse and fine-grained zones with relatively flat lying vehicle compacted zones located on old buried lift surfaces. The resulting internal dump structure is very heterogeneous with complex hydrologic, geochemical and textural characteristics. Mean precipitation on the waste rock surfaces varies with elevation from about 15 inches/year at low elevation up to approximately 30 inches per year on the very highest dumps. Depending on location, evaporation probably exceeds precipitation by a factor of two to three. The geology, topography and climatic setting combine to create continuous ARD flows, which are collected at the base of the dumps using a series of cutoff walls.

Between 1941 and 2000 the dumps were also intentionally leached for copper recovery. Acidic, high salinity water was continuously applied to the tops of the dumps, captured at the toe and recirculated. During the leach operations the emphasis was on maximizing sulfide oxidation and water contact to enhance copper recovery. Older dumps were thus constructed in a manner which did not limit ARD formation, for example by excluding limestone waste rock from leach areas and by ripping compacted or cemented surfaces to enhance permeability.

## Management Strategies

Historically, the primary control strategy for ARD at Bingham Canyon has been to ensure effective collection and treatment of water that has contacted the waste rock dumps. This was especially important during the active leaching operations because more than 20,000 gallons per minute of acidic leach water had to be managed. Currently ARD collected from the mine (~1000 gpm) is mixed with alkaline process water and tailings to neutralizing the acidity. Although the collection and treatment strategy controls offsite impacts and is protective of down gradient water resources, KUCC would like to reduce the volume of ARD generated.

Other management options which actually minimize the volume and/or acidity of the ARD that must be managed and treated can be considered. Table 1 lists a series of broad ARD management strategies that have been used or are being investigated by the mining industry. This table was compiled with both internal and external expert input for a Rio Tinto initiative that reviews ARD risks and management options at mines across the world in a variety of climatic, geologic and environmental settings. Not all of these control strategies are applicable to waste rock, and many are not practicable for use at Bingham Canyon because of its unique scale, geochemical characteristics, climate and environmental setting. Many of these strategies attempt to limit sulfide oxidation and control the rate of release of acidity, metals and soluble salts within the waste rock dump. A large number of others attempt to limit the amount of water that contacts the waste rock and transports oxidation products out of the waste rock as ARD.

In general strategies that attempt to reduce ARD impacts by limiting water contact are most practicable for use at Bingham Canyon. Water contact can be limited by 1) ensuring that up gradient surface and groundwater does not flow onto or into the waste rock and 2) minimizing the volume of precipitation that falls on to the waste rock and either infiltrates into the rock (ultimately discharging as ARD) or that contacts acid rock at the surface (running off as ARD). Many of these water management strategies can be implemented retroactively which is very important given that more than 80% of the mine's total waste rock production has already occurred. For example up gradient surface and groundwater collection systems can be installed above existing waste rock dumps to limit ARD and preserve water quality for other beneficial uses. Covers can also be constructed on existing acidic waste rock dumps to preserve runoff water quality, minimize infiltration and allow vegetation to become established.

Strategies to limit sulfide oxidation and in situ acidification are difficult or impossible to apply retroactively, particularly in the case of Bingham Canyon where all dumps are very large, heterogeneous and anisotropic, and where many older dumps were constructed to maximize sulfide oxidation and enhance copper release. For techniques that limit oxidation and acidification to work, oxygen must be excluded from the waste rock dumps on a broad scale, oxidation reactions must be inhibited at the scale of individual pyrite grains, or in-situ neutralizing reactions must occur throughout the waste rock dump very close to the points of acid generation. It would be impossible to exclude oxygen from the waste rock dumps given their large surface area and construction techniques that have created very tall, well-drained structures with numerous coarse grained rubble zones. Passivation techniques and bactericides that attempt to inhibit oxidation at the sulfide grain boundaries require intimate mixing with the waste rock mass so that the treatment is in contact with the individual sulfides. Given the great thickness of the waste rock dumps and the presence of preferential flow paths, it would not be possible to apply passivation products to the top of the dumps and deliver the treatment to the entire rock mass. Similarly blending and mixing limestone or other neutralizing agents with the waste rock requires very intimate contact to succeed and thus can not be done retroactively.

To provide significant environmental benefits, any management strategies that are used would need to provide control in the long-term. Many strategies that limit water contact can be expected to control ARD in the long term. The up gradient collection of water can be self supporting because clean water can be sold, offsetting and in many cases exceeding the cost to collect the water. Well designed covers that limit infiltration can also be expected to remain functional for

centuries. Conversely, passivation techniques and bactericide applications only provide short-term control. These products are applied in aqueous solutions and as such must be water soluble. Bench-scale and pilot-scale testing of these products has generally shown that they are rinsed from the system over time, often within a matter of a few years.

### **Applicability of Individual Strategies and Technologies**

Table 2 lists the potential ARD management strategies and presents their status, and pros and cons for use at the Bingham Canyon Mine. Many of the strategies are not applicable to waste rock, and many are not possible or practicable for use because of the physical, chemical, climatic and environmental characteristics of the waste rock dumps. Several of the potential strategies are already being implemented at the mine including:

- Selective mining and handling;
- Lowering of cutoff grade;
- Selective waste placement;
- Direct revegetation;
- Up gradient collection
- Down gradient collection and treatment; and
- Waste removal and consolidation.

Additional ARD control strategies may provide significant benefits at Bingham Canyon and the practicality to initiate or expand their use should be studied. These strategies are shown in bold on Table 2 and include:

- Up-gradient water diversion for additional drainages;
- Early recontouring to promote sulfide oxidation and depletion of acid potential on final waste rock surfaces;
- Designing final waste rock surfaces to promote runoff and inhibit infiltration;
- Expanding the use of covers to cap acid generating waste rock;
- Refining cover designs to further minimize infiltration by investigating the use of stone and release covers and limestone covers.

It is recommended that KUCC focus its research and design efforts on those strategies which offer the greatest potential benefit for control of ARD as well as increase the areas that can be successfully revegetated on the waste rock dumps.

Regards,

Rich Borden and Mark Logsdon

## Memo

**Table 1 - Potential Management and Mitigation Strategies for Chemically Reactive Mineral Wastes**  
**(Modified from Rio Tinto corporate protocols for acid rock drainage risk reviews and global programs to improve mineral waste management)**

Strategy	Features
<b>PROACTIVE PREVENTIVE MEASURES</b>	
Selective Mining	Early identification of rock masses that pose the greatest geochemical risk may allow the mine plan to be designed to avoid exposing or disturbing these materials. The additional handling, closure and water treatment costs associated with reactive materials should be included in any economic analysis when determining ore reserves and cut off grades, open pit geometry and the layout of underground workings. Early characterization of relatively benign rock masses is also needed so that materials that could be used for encapsulation, mixing or covering are identified and can be incorporated into the mine plan as appropriate.
Improved Recoveries and Production Efficiencies	Improving recovery rates during beneficiation processes mean that less of the target element or mineral remains in the resultant mineral waste where it produces no economic benefit and may actually become one of the primary contaminants of concern. Improved mining and processing efficiencies may also reduce the amount of blasting agent or reagents that are co-disposed with the mineral waste.
Lowering Cut-Off Grade	Anytime cut-off grade can be lowered the volume of waste rock produced will be reduced. Because the highest grade waste material is converted to ore when cut off grades are lowered, this process commonly removes material with the highest contaminant concentrations from waste production.
Selective Waste Placement	Waste repositories should be designed so that transport pathways that may allow contaminated water to migrate out of the waste are minimized. Where possible some of the issues that should be considered include: avoiding placement of reactive mineral wastes in areas where they may contact surface water flows or in areas where groundwater discharges to the surface; avoiding placement over highly permeable near-surface aquifers; avoiding placement immediately up-gradient of sensitive environments or facility boundaries; avoiding placement in unstable or highly erosive landforms; minimizing the ultimate footprint of the reactive mineral waste disposal areas; and avoiding placement in watersheds or in areas that have not already been impacted by previous reactive mineral waste disposal.
Up-gradient Water Diversion	In locations where surface or groundwater comes into contact with reactive mineral waste or wall rock, it is beneficial to capture the clean up-gradient water before it contacts the material. This will prevent contaminants from being mobilized and will prevent the water quality from being degraded.

Strategy	Features
Selective Handling / Encapsulation	Reactive mineral waste may be selectively handled and surrounded with benign mineral wastes like universalized oxide waste rock to limit the contact of runoff water, infiltration and groundwater, reduce direct plant uptake and animal exposure, reduce the risk posed by wind erosion, provide a growth media over phytotoxic waste, or limit the access of oxygen to sulfidic wastes. Benign material could be used for foundations in areas where water may perch at the base of the waste, or in areas where groundwater may discharge into the base of the waste pile via seeps or springs.
In-pit or Underground Disposal	This method may be viable where a mined out pit or underground workings of sufficient size are available. With effective mine planning the early closure of one of a series of pits or workings may allow for the effective disposal of reactive mineral wastes. Depending on the wall rock permeability and the location of the water table, waste placed in open pits may need to be encapsulated. For pits and underground workings located below the post-mining water table, this disposal method may be used in conjunction with sub-aqueous disposal to prevent sulfide oxidation. Backfilling to above the post-mining water table can also be used to: 1) prevent evapoconcentration and the creation of hypersaline conditions in arid or semi-arid climates, and 2) prevent the formation of pit lakes that may provide a direct exposure pathway to terrestrial animals.
Sub-aqueous Disposal	The placement of acid generating wastes below the water table or a permanent standing water column, and the permanent flooding of underground workings or pits will greatly limit the flux of oxygen into sulfide-bearing mineral wastes. This can lower the rate of acid generation and metals release by several orders of magnitude. This technique is most effective when flooding or covering is accomplished rapidly, before the material has had time to oxidize. Sub-aqueous disposal is generally not a viable control option for wastes containing contaminants that are already in a soluble form and whose rate of release is not dependent upon the supply of oxygen.
Blending/Mixing	The blending and mixing of acid generating wastes with net neutralizing materials may be used to ensure that bulk neutral pH conditions are maintained within the waste mass as a whole, either in perpetuity or for a sufficiently long enough period to allow another effective management technique to be implemented. The mixing of inert mineral wastes with other types of reactive wastes may also disperse and dilute the contaminant sources so that contact water that discharges from the waste meets the water quality criteria. This control technique may be difficult to implement because of the establishment of preferential flow paths within the waste, because of armoring of neutralizing rock surfaces, and because acidified pockets are likely to form within the waste column. Proper implementation of the technique requires very good ore and waste characterization and control, coupled with sequential mining and good dispatch control to ensure that reactive and benign wastes are intimately mixed at the appropriate ratios.
Enhanced Tailings Consolidation	Techniques that enhance tailings consolidation such as the construction of underdrains, ensuring subaerial placement, controlling the rate of rise, active removal of pore water with extraction bores, or initial placement as thickened or paste tailings will create a more stable material with lower hydraulic conductivity. If solutes within the pore water pose an environmental risk, enhanced consolidation will also reduce the total contaminant volume and lower the potential flux of contaminants that could discharge from the tailings.
Co-disposal	Materials with different physical characteristics may be mixed for co-disposal to enhance stability and resistance to erosion or to reduce permeability. This technique may be applied to the co-disposal of tailings with waste rock. The mixing of tailings and waste rock may create a well graded material that typically has lower hydraulic conductivity, higher water storage capacity and that is relatively resistant to erosion. The geochemical compatibility of mixtures and both the geochemical and hydraulic performance require evaluation. Techniques to deposit thickened or paste tailings that are not segregated into coarse and fine fractions, or segregated into sulfide-depleted and sulfide-enriched fractions, may also provide lower hydraulic conductivity, maintain saturation and, if the parent material is net neutralizing, may prevent the creation of net acid generating tailings.

Strategy	Features
Mineral Segregation	<p>Under some circumstances it may be possible to preferentially float or otherwise separate reactive minerals from the larger mass of inert minerals within the tailings. For example, gangue sulfides such as pyrite may be separated from the bulk of the tailings by flotation to reduce their acid potential and ensure they are net neutralizing. Metals that are associated with sulfide minerals may also be preferentially removed by this technique. The relatively small volume of waste sulfide material can then be specially handled to minimize its environmental risks.</p>
Compaction During Placement	<p>Reactive waste rock or overlying benign material may be compacted during placement to lower the hydraulic conductivity of the material and limit the potential flux of water through the compacted layer. Compaction may also aid in the establishment of capillary breaks and/or perched water tables to form saturated conditions within the compacted layers, which will inhibit the flux of oxygen. Engineered compacted layers should be specially constructed with specific purpose equipment as mine vehicles that provide a dense traffic surface, do not form a uniform hydraulic seal and water flow continues down the small but numerous preferential flow paths within the densified traffic layer.</p>
Liners	<p>Liners can be constructed under reactive mineral wastes to allow capture of contact water that would normally discharge to the surface or to groundwater. Liners can be simple and relatively inexpensive or complex and very expensive depending upon the required performance criteria (generally the allowable design leakage rate). Complex liners are generally only practicable for use with small volumes of very reactive mineral waste.</p>
Temporary Synthetic Covers	<p>Synthetic covers such as HDPE sheeting may be used to temporarily cover reactive mineral wastes or ore stockpiles. This isolates the material from precipitation and greatly limits the volume of contact water that may discharge from the material. This is not a viable long-term strategy to limit water contact because the synthetic material will degrade with time, but it can be used on a short-term basis until the ore is processed or the final closure strategy for the mineral waste is implemented. However, when temporary covers are removed dissolution of salts may occur that produces a large spike in contaminants of concern.</p>
Incorporation of Organic Matter and/or Nutrients	<p>Incorporation of organic matter or nutrients into mineral wastes can promote the establishment of reducing conditions within the waste material (inhibiting sulfide oxidation), may reduce metals solubility by providing sorption sites or could be used to promote biological activity to break down organic reagents or blasting residues. Organic matter can also provide a carbon and nutrient source to promote the establishment of sulfate-reducing bacteria, potentially removing dissolved sulfate and metals from pore waters.</p>
Accelerated Sulfide Oxidation	<p>In specially designed heap leach pads, it may be possible to accelerate sulfide oxidation processes, depleting all the reactive gangue sulfide minerals before closure. This would help reduce the risk of long-term contaminant release from the mineral waste.</p>
	<p>This technique would likely only be viable for copper heap leach pads and other operations that are already designed to maximize the oxidation of sulfide ore minerals. However, costs are likely to be high and the viability of this option has not been proven at an operational scale.</p>
Micro-Encapsulation (passivation)	<p>This process involves the coating of mineral wastes or pit walls with products that encapsulate sulfide surfaces and inhibit oxidation reactions. The mechanism involves mixing the reagents with waste or spraying pit walls with treatment solutions. Treatments that are being investigated include phosphate, polymer and potassium permanganate application. However, these techniques are likely to be costly on a per ton basis, there may be potential for environmental problems associated with the use of some reagents, retroactive treatment of large waste storage facilities is unlikely to be successful and the long-term viability of the techniques has not been proven at an operational scale.</p>

Strategy	Features
Bactericide Application	Abiotic sulfide oxidation rates are typically several times slower than biologically-controlled oxidation rates. Bactericides such as thiocyanate that inhibit the growth of sulfide-oxidizing micro-organisms can substantially slow ARD generation rates. However, these techniques are likely to be costly on a per ton basis, there may be potential for environmental problems associated with the use of these bactericides., retroactive treatment of large waste storage facilities is unlikely to be successful and the long-term viability of the techniques has not been proven at an operational scale.
<b>REACTIVE REMEDIAL MEASURES</b>	
Recontouring to Promote Runoff and Inhibit Infiltration	Waste surfaces can be recontoured to prevent precipitation from pooling in low points on the surface and/or to allow precipitation to be more efficiently shed from the surface. The surface can be contoured to naturally remove precipitation from the surface via runoff, or low points can be established from which runoff is collected and piped off of the surface.
Direct Revegetation	Some waste surfaces may be directly revegetated after minor physical or chemical modification such as ripping to reduce compaction, addition of liming agents to increase the pH to near neutral, or the addition of organic matter. The establishment of vegetation can significantly increase evapotranspiration and greatly reduce the amount of water that infiltrates into the underlying waste material. Direct revegetation may allow many of the benefits of a store and release cover to be realized without the need to import large volumes of cover material.
General Purpose Covers	Covers can be constructed over reactive wastes using inert mineral waste, imported fill or soil to: 1) reduce infiltration and preserve runoff water quality, 2) allow vegetation to become established on phytotoxic wastes, 3) limit plant uptake of bioavailable metals in the underlying waste, 4) limit wind transport of reactive wastes, and 5) limit direct exposure pathways for animals and humans to toxicants and/or radiation sources in the underlying wastes. If required, covers can also be designed to limit water infiltration or oxygen ingress into the underlying mineral waste or to provide alkalinity to the underlying waste.
Infiltration or Oxygen Limiting Covers	Two general types of covers to limit oxygen and/or water ingress may be constructed on top of existing mineral waste 1) low permeability covers with or without capillary breaks to limit the flux of oxygen and water into the underlying waste or the flux of radon out of the waste, or 2) store and release covers that limit the amount of water that may infiltrate into the underlying waste. In general low permeability covers are best suited to wet climates and store and release covers are best suited to dry climates (where evaporation is at least twice precipitation). Low permeability covers that inhibit the entry of oxygen generally require that nearly saturated conditions be maintained within the cover at all times. Low permeability covers are often subjected to natural processes that may cause degradation in performance over time such as bioinfiltration by plants and animals and increasing permeability because of natural freeze/thaw and wetting/drying cycles. It is important for compacted layers to be protected from these processes by a thick overlying cover layer. The performance of most store and release cover systems is strongly dependent upon the thickness and texture of the cover material (i.e. high moisture storage capacity and low susceptibility to cracking) as well as the vegetation density, rooting characteristics and species composition of vegetation that is established on the cover to maximize evapotranspiration rates. Covers can be simple, thin and relatively cheap or complex, thick and relatively expensive depending on the required performance criteria (generally the design allowable flux of infiltration or oxygen through the cover and into the underlying reactive mineral waste). In some climatic conditions, store and release covers may not be practicable.
Alkaline Covers	Under certain climatic and geochemical conditions it may be beneficial to construct covers with relatively reactive carbonate material. The carbonate can provide enough alkalinity to the underlying waste via infiltrating precipitation to inhibit widespread acidification and ARD or to increase the thickness of underlying neutralized waste, allowing plants to root more deeply.

Rinsing	Rinsing can be used to flush soluble constituents from mineral wastes. Generally several pore volumes must be exchanged to reduce concentrations to acceptable levels. If all of the potential contaminants are not present in a readily soluble form, then rinsing is unlikely to be viable. For example rinsing would not be a viable alternative for sulfide-bearing wastes until almost all of the sulfides have been oxidized. Rinsing, however, with mixed success has been practiced for cyanide heap leach pads where water application infrastructure is already in place and the removal of soluble CN is the primary goal.
Flooding	The permanent flooding of existing mineral wastes, open pits and workings can limit the access of oxygen to the waste material and greatly restrict the rate of sulfide oxidation. Ideally flooding should occur as soon as the waste material is exposed. Waste materials that have undergone long periods of sub-aerial storage prior to flooding may contain abundant soluble sulfide oxidation products that may be released when the material is initially contacted by water. It may be necessary to add neutralizing agents to weathered materials that have acidified before they are flooded. Flooding is generally not a viable control option for waste containing potential contaminants that are already in a soluble form and whose rate of release is not dependent upon the supply of oxygen.
Down-gradient Collection and Active Management of Contact Water	Required for sites where contaminated contact water is already discharging from the mineral waste. Involves the capture of impacted surface and/or groundwater for treatment and disposal. Potential collection and recovery systems may include gravity flow into catchment ponds, drains and trenches as well as pumping from pits, underground workings and extraction wells. Management options include active water treatments such as the addition of liming agents; the use of reverse osmosis or wetlands treatment for polishing; internal mixing and dilution with controlled release to receiving water bodies; evaporative disposal; reuse in the process; and construction of reactive barriers.
In-Pit Water Treatment	The water chemistry of pit lakes may be manipulated in situ to promote physical or chemical conditions and biological processes that improve or maintain water quality. Some examples include: 1) controlling the depth of flooding to completely cover acid generating wall rock zones, to prevent water from contacting acid generating zones, or to create lakes that are unlikely to turn over, 2) the direct addition of liming agents to maintain a neutral pH and inhibit sulfide oxidation below the water surface, 3) the addition of fertilizer to promote biological activity that removes metals from the water column and helps establish anaerobic conditions at depth and 4) the addition of sorbing agents such as iron to remove dissolved metals from solution.
Demonstrating Hydrological Containment	For open pits that intersect the water table in arid and semi-arid climates it may be possible to demonstrate hydrological containment of solutes and contaminated water within the pit. Evaporative losses from the pit lake may be sufficient to maintain radial groundwater flow towards the pit in perpetuity. Containment can be enhanced by reducing the volume of runoff water that reaches the pit floor or by pumping and treating enough pit water to keep the lake level below water levels in the surrounding bedrock.
Waste Removal and Consolidation	In some cases it may be beneficial to move tailings and waste rock from one location to another if they are broadly dispersed or located in a particularly sensitive location. The selective removal and consolidation of strongly reactive mineral wastes into a smaller footprint may allow for better mitigation, containment and control of the potential contamination.

**Table 2 – Applicability of Potential ARD Management Strategies for Implementation at the Bingham Canyon Waste Rock Dumps**

<b>Strategy</b>	<b>Status</b>	<b>Pros at Bingham</b>	<b>Cons at Bingham</b>
<b>PROACTIVE PREVENTATIVE MEASURES</b>			
Selective Mining	In use – benign waste rock is being stockpiled for potential use as cover material	-Can provide a growth media and construction material for covers -Limits the need for imported fill	-Stockpiling requires double handling -Chemically benign but coarse material may not make ideal growth media or cover material
Improved Recoveries and Production Efficiencies	Not pertinent to waste rock		
Lowering Cut-Off Grade	In use – cutoff grades have been lowered consistently over the century of mine life	-Reduces volume of waste rock per pound of copper produced -Reduces copper loading to waste rock dumps	-May increase the amount of pyrite reporting to tailings impoundment
Selective Waste Placement	In use – waste is preferentially placed on existing waste rock surface and in drainages already impacted by waste rock disposal	-Reduces contact water volume (from precipitation and infiltration) -Reduces waste rock footprint and land impacts -Limits potential areas of new groundwater impacts	
Up-gradient Water Diversion	<b>In use but could be expanded</b> Flows are currently captured in upper Dry Fork, Zelnor and Sap and exploring options in other drainages	-Reduces contact water volume and ARD flows -Preserves water quality for other beneficial uses -Reduces head driving contaminated groundwater flow	<b>-May not be cost effective</b> compared to other management strategies in some drainages -Mine expansions could damage infrastructure in some drainages
Selective Handling/Encapsulation	In use – benign waste rock is being stockpiled for potential use as cover material	-Can provide a growth media and construction material for covers -Limits the need for imported fill	-Stockpiling requires double handling -Chemically benign but coarse material may not make ideal growth media or cover material
<i>In-pit or Underground Disposal</i>	<i>Not in use</i>	<i>-Could reduce footprint and mass stored in waste rock dumps</i>	<i>-Open pit mining method does not allow significant waste rock storage</i>

		-Some acid generating rock could be flooded controlling ARD generation	within a single active pit -Waste rock stored in pit could have a deleterious effect on long term water quality unless it is rapidly flooded after mining
Sub-aqueous Disposal	<i>Not in use</i>	-Some acid generating rock could be flooded at closure if it is placed in the bottom of the pit	-Subaqueous disposal is not possible for the waste rock dumps -Subaqueous disposal is only feasible in the lowermost open pit but in pit disposal is not practicable on a large scale (see above)
Blending/Mixing	<i>Not in use</i>		-Can not be retroactively applied to existing waste rock -There is insufficient acid neutralizing waste rock available to use this strategy
Enhanced Tailings Consolidation Co-Disposal	Not pertinent to waste rock		-Can not be retroactively applied to existing waste rock -Co-disposal of tailings and waste rock is not practicable due to large distance and elevation gains, and lack of infrastructure -Not a proven technology
Mineral Segregation Compaction During Placement	Not pertinent to waste rock <i>Not in use – except for incidental truck compaction</i>	-Could increase runoff on compacted surfaces, reducing infiltration if the runoff water is captured and removed from the dump surface	-Compacted surfaces inhibit plant rooting and establishment -Compaction will not prevent infiltration through coarse waste rock -Freeze/thaw, wetting/drying, plant rooting and animal burrowing will increase the permeability of compacted layers through time -No infrastructure currently exists for removal of runoff water from waste

<b>Liners</b>	<i>Not in use</i>	<b>rock surfaces</b>	<ul style="list-style-type: none"> <li>-Liners can not be retroactively placed under existing waste rock dumps</li> <li>-There are no plans to significantly increase waste rock footprint</li> <li>-Groundwater collection and treatment systems are already in place</li> <li>-Could cause geotechnical stability issues due to low coefficient of friction</li> </ul>
<b>Temporary Synthetic Covers</b>	<i>Not in use</i>		<ul style="list-style-type: none"> <li>-Most of the waste rock surfaces are active so even temporary covers could not be placed</li> <li>-Not practicable to install covers on such a large surface area</li> <li>-Cover performance would degrade with time so not a long term solution</li> <li>-Could not be incorporated retroactively into the waste rock mass</li> <li>-Unlikely to ever produce reducing conditions within the waste rock</li> </ul>
<i>Incorporation of Organic Matter and/or Nutrients</i>	<i>Not in use</i>		<ul style="list-style-type: none"> <li>-Reduces limestone demand for soil applications on reclaimed surfaces</li> <li>-May increase the number of surfaces that can ultimately be reclaimed by direct planting or planting into thin covers</li> </ul>
<b>Accelerated Sulfide Oxidation</b>	<b>Passively in use but could be expanded – Early recontouring and creation of final waste rock surface will allow time for freshly exposed sulfides near the surface to oxidize before closure</b>		<ul style="list-style-type: none"> <li>-Early recontouring and creation of final waste rock surface will allow time for freshly exposed sulfides near the surface to oxidize before closure</li> </ul>
<i>Micro-Encapsulation (passivation)</i>	<i>Not in use</i>		<ul style="list-style-type: none"> <li>-Not possible to implement retroactively</li> <li>-Not a proven technology, viability has never been demonstrated at an operational scale</li> <li>-Not a permanent solution, treatments are leached out of the</li> </ul>

		waste rock or break down with age -Many of the reagents are toxic and large scale application could damage groundwater quality and inhibit revegetation -Very costly on a per ton basis -Some technologies will not work on waste rock that has already acidified
Bactericide Application	Not in use	Not possible to implement retroactively -Not a proven technology, viability has never been demonstrated at an operational scale -Not a permanent solution, treatments are leached out of the waste rock or break down with age -The bactericides are toxic and large scale application could damage groundwater quality -Very costly on a per ton basis
REACTIVE REMEDIAL MEASURES		-Capture and removal of runoff will limit infiltration and reduce ARD generation -Well designed runoff collection and conveyance systems will reduce potential for erosion -Cannot be permanently implemented until final waste rock surfaces are created -Geometry of some waste rock dumps will make it difficult to convey water off of the dump surface
Recontouring to Promote Runoff and Inhibit Infiltration	Not in use – could be designed and implemented at closure	-Increases evapotranspiration rates compared to bare surfaces, reducing infiltration and ARD generation -Begins the slow process of organic matter enrichment and soil creation -Will lead to a diverse, healthy
Direct Revegetation	In use- approximately 200 acres of waste rock have been reclaimed so far	-Not possible on pyrite-rich waste rock surfaces -Poor results on coarse grained waste rock surfaces -Relatively slow establishment of dense vegetation cover -Potential Evapotranspiration is not maximized on all surfaces

		native plant community in the long term	
<b>General Purpose Covers</b>	In use but could be expanded – approximately 330 acres were capped with an 18 inch growth media cap in the 1990s, Capping of the lower Bingham Canyon dump slope (approximately 140 acres) with a mean 24 inch cover is planned	<ul style="list-style-type: none"> <li>-Preserves runoff water quality</li> <li>-Allows revegetation of pyrite-rich waste rock surfaces</li> <li>-Increases evapotranspiration rates compared to bare surfaces, reducing infiltration and ARD generation</li> </ul>	<ul style="list-style-type: none"> <li>-May not optimize evapotranspiration to the maximum extent possible</li> <li>-Cover thickness may not be sufficient to allow woody shrubs and trees to become established everywhere</li> </ul>
<i>Low Permeability infiltration limiting covers</i>	<i>Not in use</i>		<ul style="list-style-type: none"> <li>-Freeze/thaw, wetting/drying, and biointrusion would degrade performance of compacted layers</li> <li>-Differential dump settling and movement would compromise integrity of compacted layers</li> </ul>
<b>Store and Release infiltration limiting covers</b>	Not in use but should be investigated further.	<ul style="list-style-type: none"> <li>-Climatic setting (evaporation to precipitation roughly 2:1 or greater indicates store and release covers could perform well</li> <li>-Well designed store and release covers could significantly decrease infiltration and ARD flux compared to bare surfaces, direct planting or general purpose covers</li> </ul>	<ul style="list-style-type: none"> <li>-Although store and release covers could significantly reduce infiltration, under local climatic conditions it is unlikely that mean infiltration could be ever be reduced to near zero</li> </ul>
<b>Oxygen Limiting Covers</b>	<i>Not in use</i>		<ul style="list-style-type: none"> <li>-Waste rock dump geometry, particularly tall angle of repose faces would make it very difficult to limit oxygen ingress</li> <li>-Semi-arid climate with distinct wet and dry seasons would make it impossible to maintain saturated conditions in cover material</li> <li>-Freeze/thaw, wetting/drying, and</li> </ul>

	<b>Alkaline Covers</b>	<b>Not in use but should be investigated</b>	<ul style="list-style-type: none"> <li>-Significant portion of the benign waste rock being stockpiled is limestone</li> <li>-Infiltration through a limestone cover may deliver sufficient alkalinity to advance a thin (several feet?) neutralization front into the underlying waste rock</li> <li>-This will allow plants to root more deeply, increasing the effective store and release thickness of the cover and further limiting infiltration</li> </ul>	<ul style="list-style-type: none"> <li>-Will only affect very shallow waste rock, negligible impact on overall dump geochemical behavior other than aiding in vegetation establishment and thereby limiting infiltration</li> <li>-Limestone waste rock is commonly blocky and its texture is not ideal as a growth media or as a store and release cover material</li> </ul>	<ul style="list-style-type: none"> <li>-Even though water quality is generally improving, waste rock dump contact water will always require active collection and treatment</li> <li>-After closure when water treatment and sludge disposal becomes much more costly, limiting the volume of ARD that must be treated becomes more important than the benefits of flushing with infiltrating precipitation</li> </ul>
	<b>Rinsing</b>		<p>Passively in use – Infiltration of clean precipitation through bare waste rock surfaces is flushing residual copper heap leach water, acidity and salts from the waste rock</p>	<ul style="list-style-type: none"> <li>-Mean acidity and total dissolved solids of ARD discharging from the toe of the waste rock dumps is decreasing</li> <li>-Water quality should continue to improve as extremely saline heap leach fluids drain down from the system and as more clean infiltration water enters the system</li> <li>-Relatively high infiltration rates through the dumps during operation do not impose a large cost burden because of cost effective water treatment and sludge disposal by mixing with tailings</li> </ul>	<ul style="list-style-type: none"> <li>-Only viable location to flood waste</li> </ul>
	<b>Flooding</b>		<i>Not in use</i>		

		<p><i>rock is in the bottom of the open pit</i>  <i>-Weathered waste rock stored in pit could have a deleterious effect on long term water quality as stored sulfide oxidation products are flushed out</i>  <i>-Returning waste rock from the dumps to bottom of the open pit is not practicable</i></p>
Down-gradient Collection and Active Management of Contact Water	In use – primary control strategy at Bingham Canyon, water quality down gradient from collection systems is improving	<ul style="list-style-type: none"> <li>-Existing collection systems are very effective at capturing contaminated water before it reaches down-gradient aquifers</li> <li>-Co-disposal of ARD with tailings limits lime treatment and sludge disposal costs</li> </ul>
In-Pit Water Treatment Demonstrating Hydrological Containment	Not Pertinent to Waste Rock	<ul style="list-style-type: none"> <li>-Reduced waste rock footprint allowing vegetation establishment and limiting contact with precipitation and surface flows</li> </ul>
Waste Removal and Consolidation	Largely completed – Waste rock was removed from approximately 80 acres of land east of the waste rock dumps	<p>Strategies in normal font are in already in use at KUC or are not applicable to waste rock management. Strategies in italics are not practicable for use on the KUC waste rock dumps because they are incompatible with the environmental, climatic or operation setting. Strategies in bold are not in use or are not fully implemented at KUC but may provide additional ARD management benefits and should be considered or expanded.</p>